Algorithm Baseline for L1 Product and Calibration

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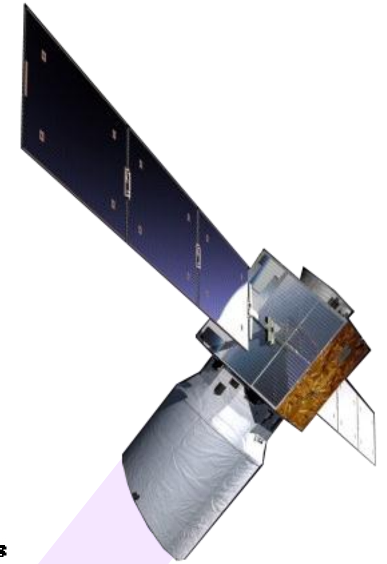
DLR

DoRIT

Physics Solutions

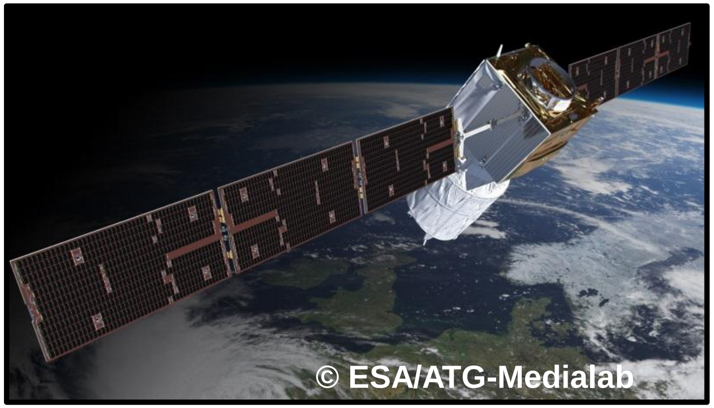
METEO FRANCE
Toujours un temps d'avance



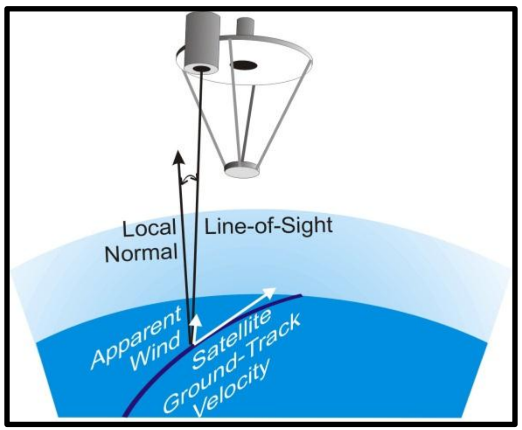
in close cooperation with
ESA, Airbus Defense & Space,
L2 Algorithm Team from
ECMWF, KNMI

DLR

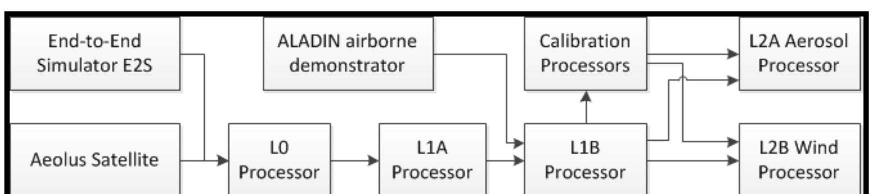
Outline of the talk



- How are winds measured by ALADIN and can be retrieved?



- Why is a calibration needed for ALADIN and how is it performed?



- What are the processing steps and challenges for wind retrieval up to Level 1?

It started here at ESRIN, Frascati in 1968

with Giorgio Fiocco
(1931-2012)

at European Space Research Institute, Frascati
1968-1971

JOURNAL OF THE ATMOSPHERIC SCIENCES

Measurement of Aerosol Motion and Wind Velocity in the Lower Troposphere by Doppler Optical Radar

G. Benedetti-Michelangeli, F. Congeduti and G. Fiocco[1]

European Space Research Institute (ESRIN), Frascati (Rome), Italy

(Manuscript received 19 October 1971, in revised form 6 March 1972)

ABSTRACT

An optical radar has been used to measure the radial wind velocity component in the lower troposphere by detecting interferometrically the bulk Doppler shift affecting the echoes from atmospheric aerosols. The measurements, carried out at night, have basically utilized a highly coherent single-frequency Ar^+ laser in the transmitter, and a small telescope, a scanning spherical Fabry-Perot interferometer, and a photon counting system in the receiver.

Doppler frequency shift differently affecting echoes from molecules and aerosols. In a backscattering experiment the frequency shift Δf associated with a radial component of velocity v_z is given by $\Delta f \sim f 2 v_z / c = 2 v_z / \lambda$. Thus at a wavelength $\lambda = 0.4880$ µm, a velocity component $v_z = 10$ m s^{-1} will give a frequency shift $\Delta f = 41$ MHz. The observations described here were carried out with the optical radar looking at the zenith; no large values of vertical velocities were then expected and the resolution available was not adequate for wind velocity measurements. On the other hand, random velocities associated with thermal molecular motions are much larger and were detectable.

For non-interacting, randomly distributed molecules with a Maxwellian distribution of velocities, the spectrum of echoes should be expressed by the familiar Gaussian curve. This disregards correlations arising because of interactions

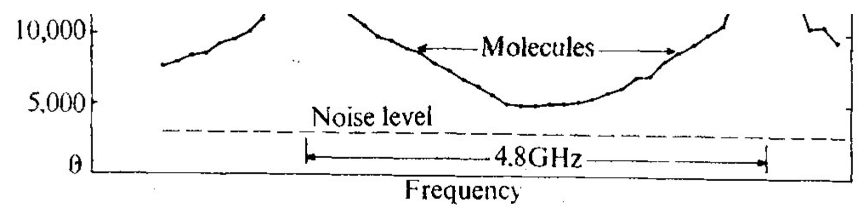


Fig. 1 Spectrum of echoes from air. Contributions of molecules from aerosols can be separated.

Benedetti-Michelangeli et al. (2003). Annals Geophysics

Aeolus – the first wind lidar in space - first time that retrieval algorithms for spaceborne wind lidars are developed

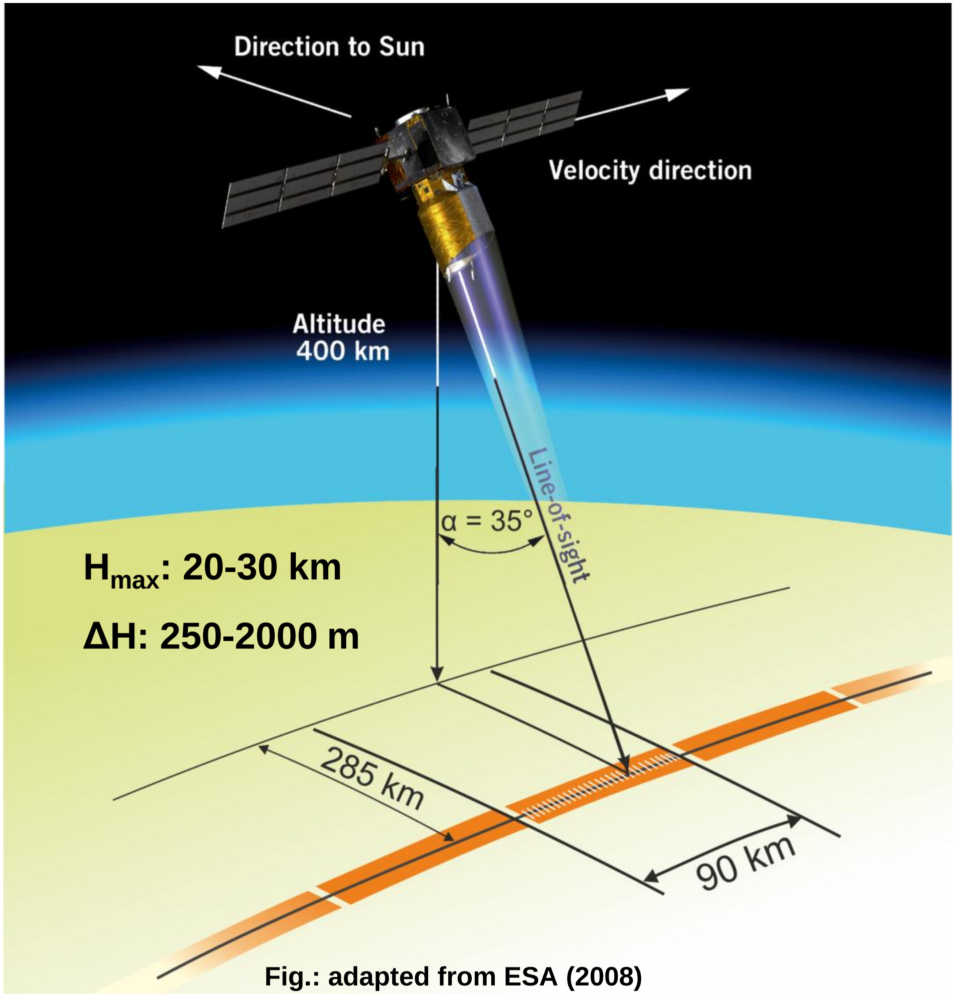


Fig.: adapted from ESA (2008)

- High requirement on **random error** (precision):
  1 m/s (0-2 km) to 2 m/s (2-16 km) HLOS
  => mainly determined by photon Poisson noise

  Algorithms for quality control and error quantifiers are affected

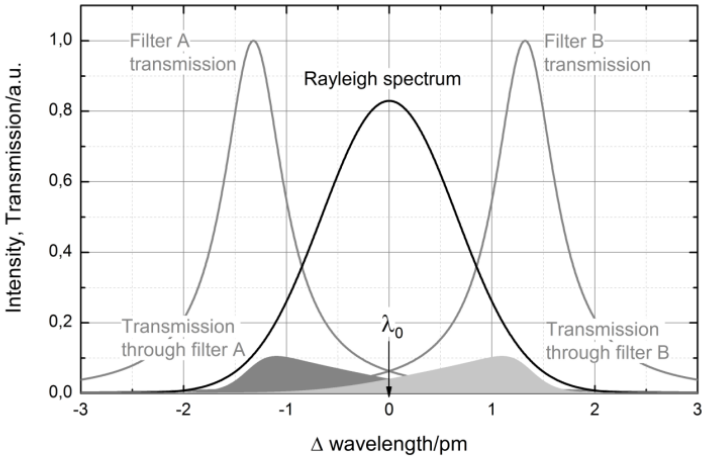
- Very demanding requirements for the **systematic error** (accuracy)**:** bias <0.4 m/s and linearity error <0.7 % of actual wind speed => mainly determined by instrument stability and calibration

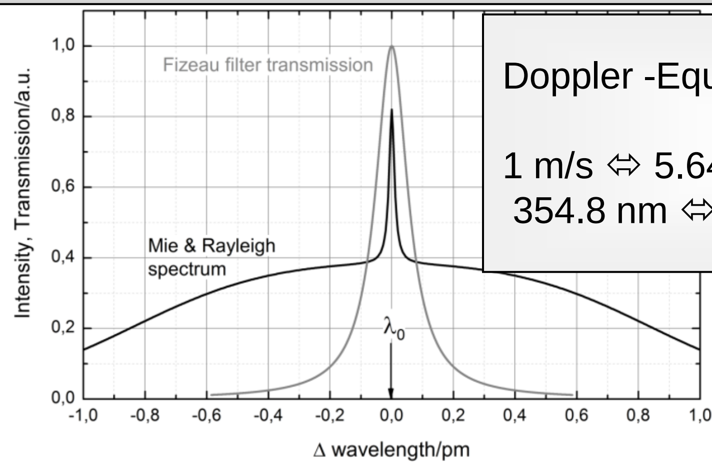
  Strong influence of algorithms for wind retrieval, calibration, ground-correction and bias characterisation and correction

- Wind products need to be available for NWP users within 3 hours after observation => different to other lidar missions and science-driven missions

  Monitoring of Aeolus wind products with NWP models, but strong need to provide consoli-dated and validated wind products within some months after launch

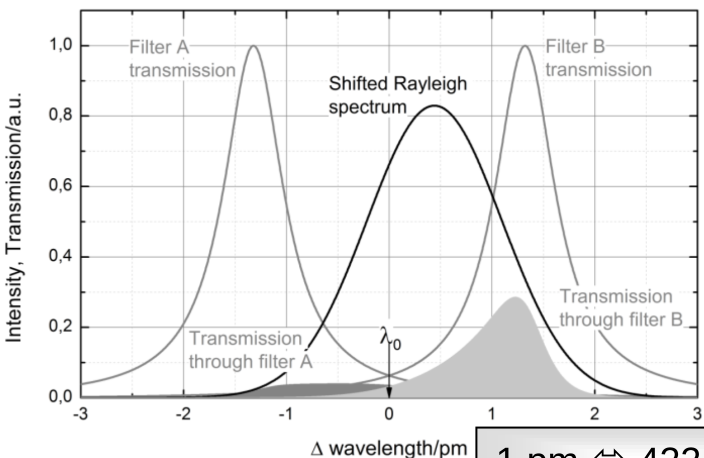
Principle of Rayleigh and Mie spectrometer for ALADIN





Doppler -Equation: $\Delta f = 2 f_0 \frac{v_{LOS}}{c}$

1 m/s ⇔ 5.64 MHz ⇔ 2.37 fm
354.8 nm ⇔ 844.955 THz



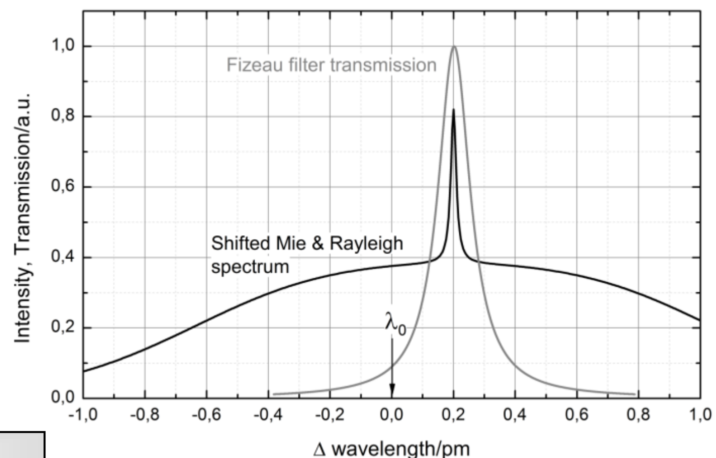


Fig.: Reitebuch (2012): Wind Lidar for Atmospheric Research, in Springer Series

1 pm ⇔ 422 m/s

Rayleigh wind sensitivity **0.3% / m/s**

=> Determine signal intensity with an accuracy in the order of 0.05% to 0.5%
=> **offset corrections and calibration**

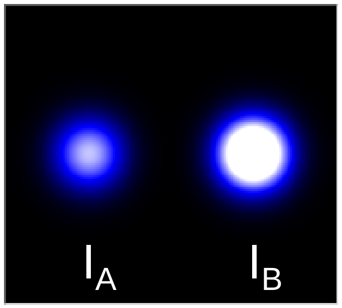
Mie wind sensitivity **18 m/s per pixel**
+ Mie fringe width **30 m/s**

=> Determine centroid of a signal, which is 30 m/s broad (FWHM) with an accuracy of 1/100 to 1/20 of a pixel width **=> high SNR and QC**

Why are calibrations needed for direct-detection wind lidar?

Rayleigh spots

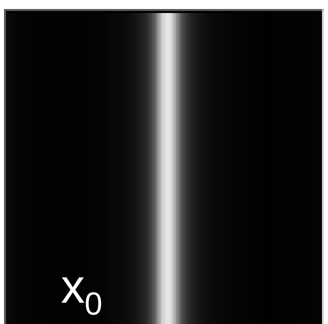
16 Pixel



16 Pixel

Mie fringe

16 Pixel



16 Pixel

$$R = \frac{I_A - I_B}{I_A + I_B} \quad \text{or} \quad R = \frac{I_A}{I_B}$$

Instrument Response R

$$R : \hat{x}_0 \text{ centroid pixel}$$

Measure R for v_{LOS}=0 m/s (nadir pointing) and vary Δf by changing laser frequency

Measure R(Δf)

Calibration R(Δf)

Compute R(Δf)

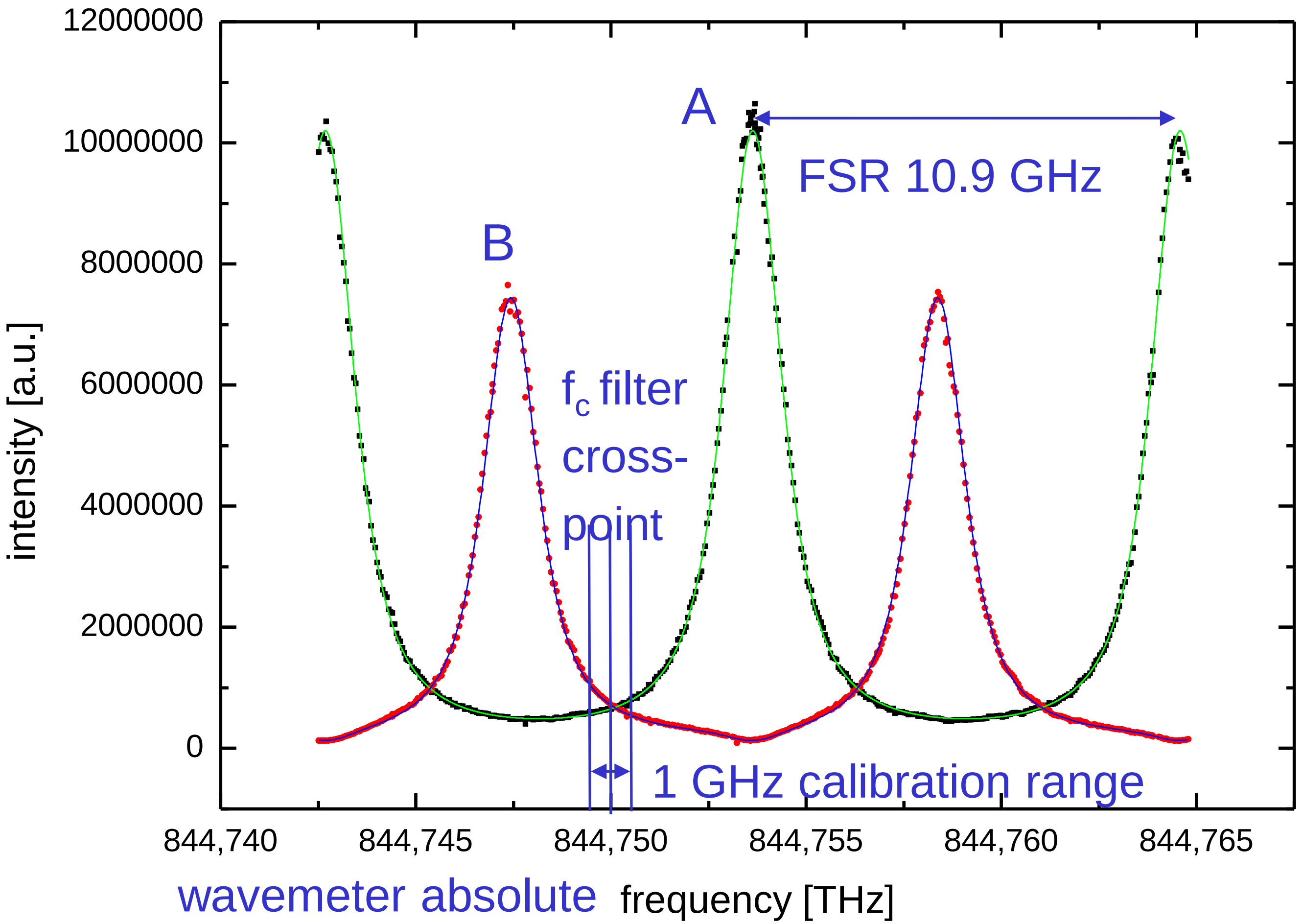
Lineshape model I(f)
Rayleigh-Brillouin I(f)=f(T,p,h)
and laser lineshape I(f)

Instrument function T(f)
for Rayleigh and Mie spectrometer

Doppler frequency Δf and LOS wind v_{LOS}

$$\Delta f = 2 \bullet f_0 \bullet \frac{v_{LOS}}{c}$$

Rayleigh and Mie Instrument functions are determined on ground and in-orbit



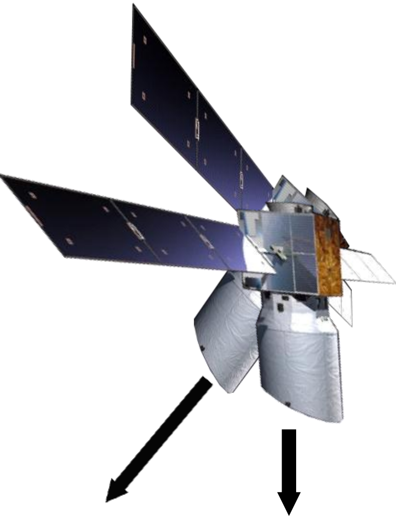
A2D measurements and fits with Airy-function convolved with Gaussian Defect Function + Fizeau reflection

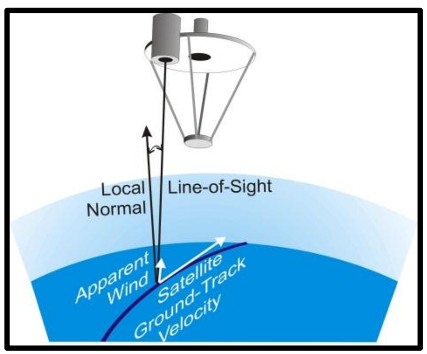
STD from several characterisations:

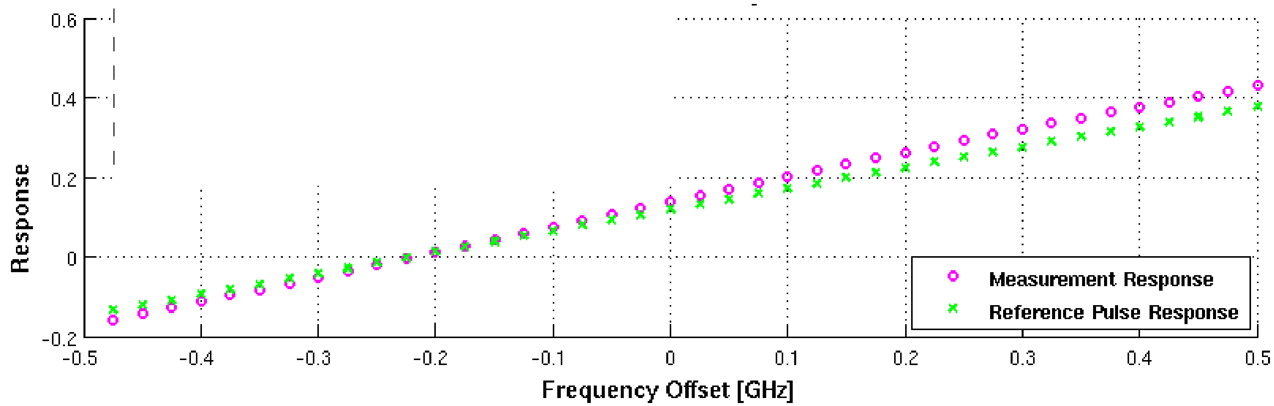
FSR: 23 MHz (0.2%)

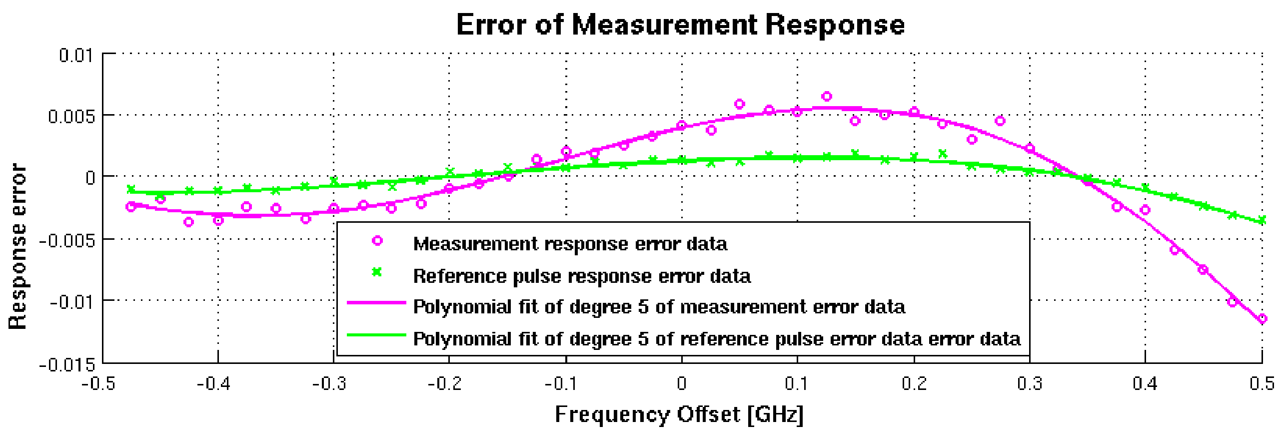
FWHM: 30 MHz (1.8%)

Calibration of Rayleigh/Mie spectrometer response



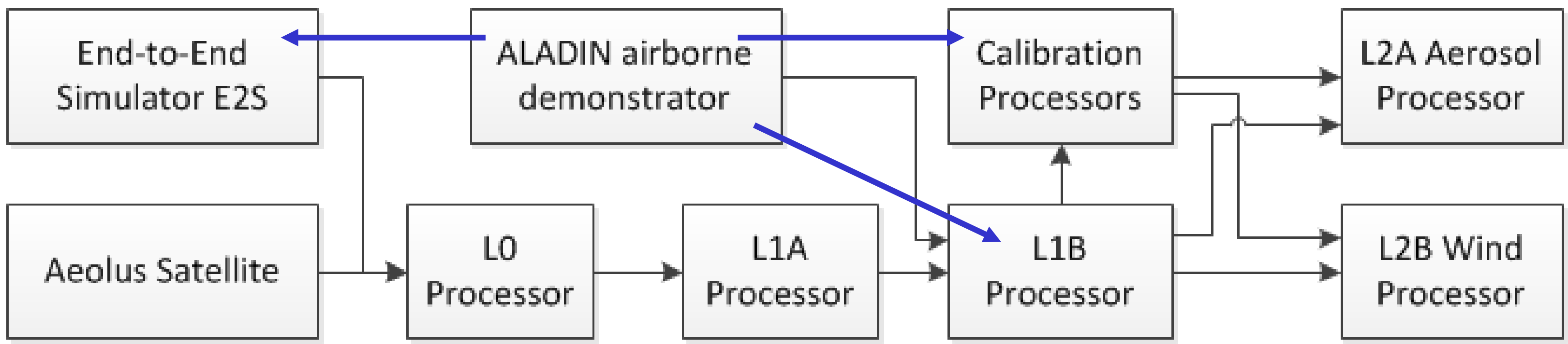


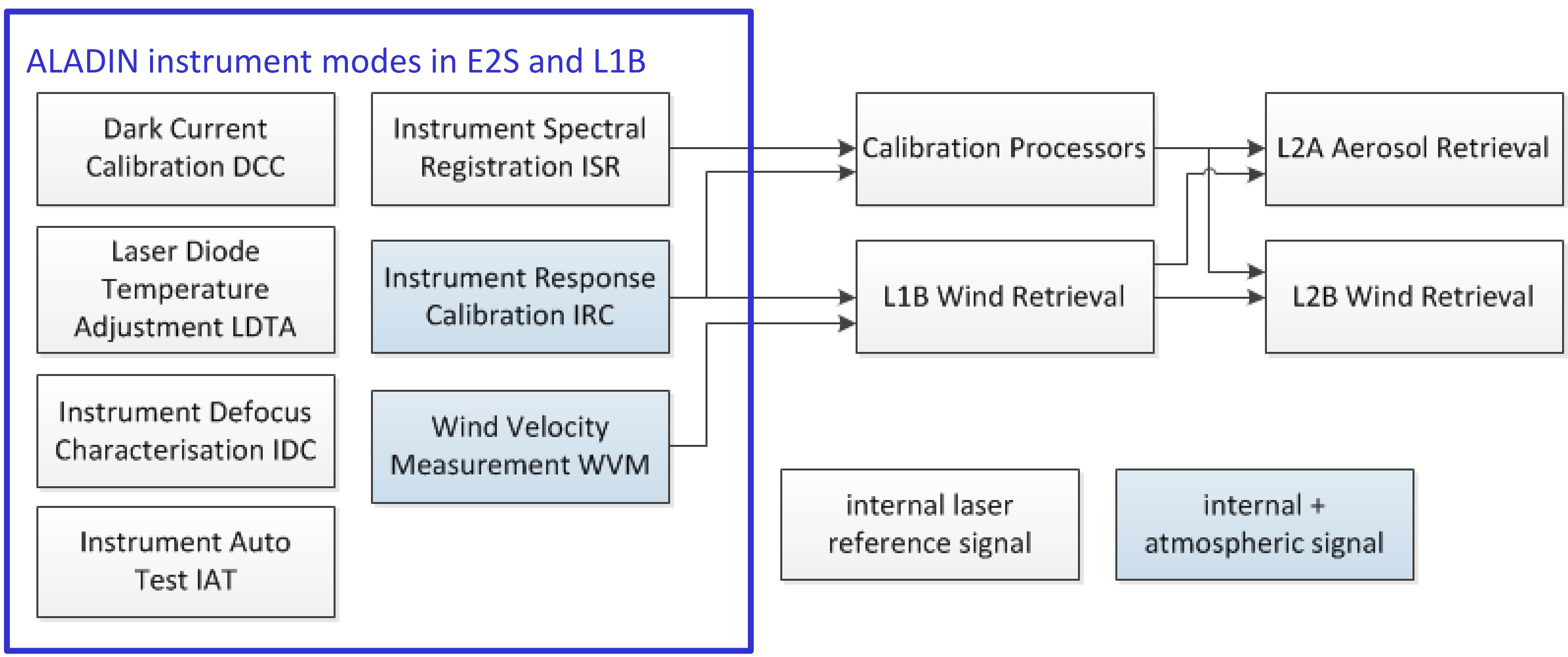




Characterization of Internal and Atmospheric Response for different laser frequencies for Mie and Rayleigh spectrometer => fit coefficients used for L1 wind retrieval

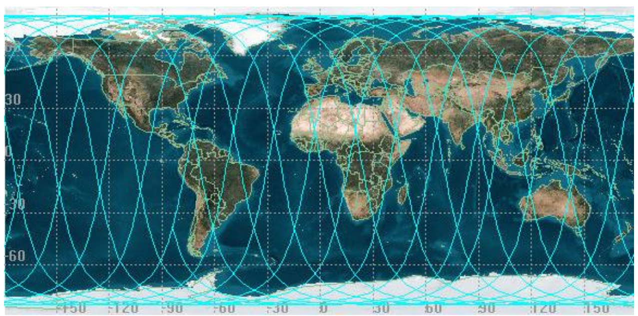
Chain of processors for Aeolus

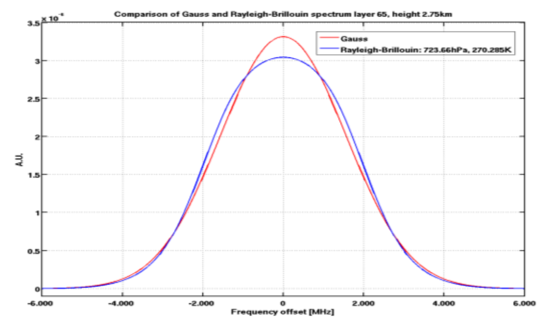


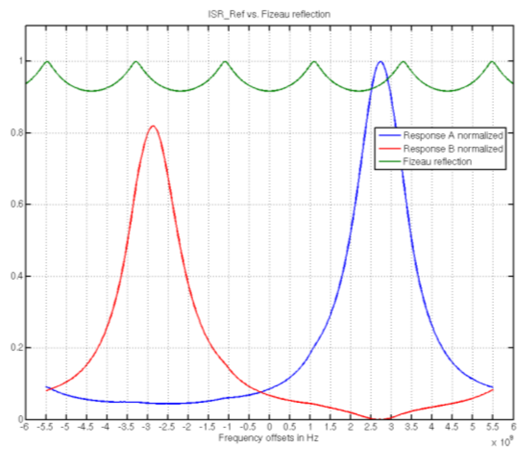


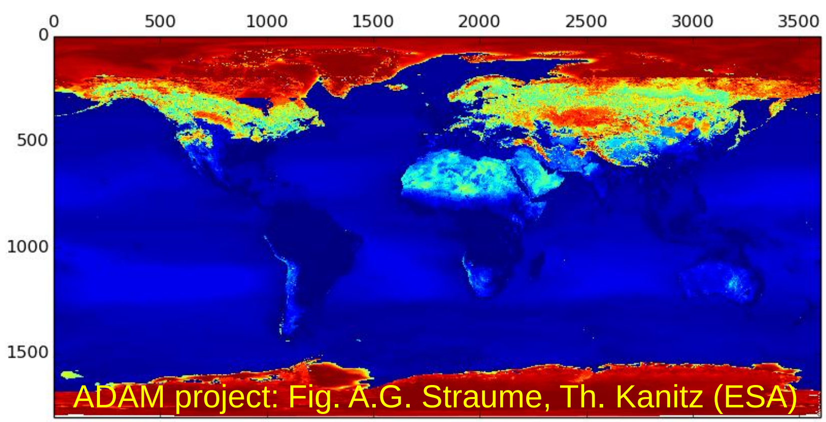
The Aeolus End-to-End Simulator E2S

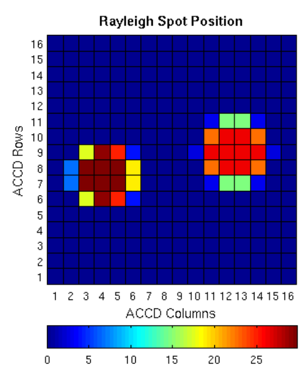
Orbit + Pointing → **Atmosphere + Ground** → **ALADIN instrument** → **Data formatter**

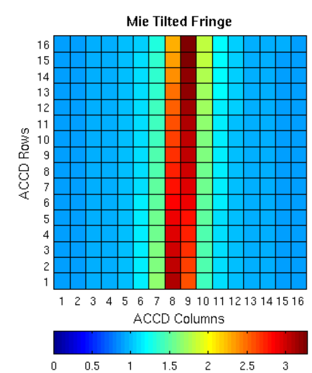




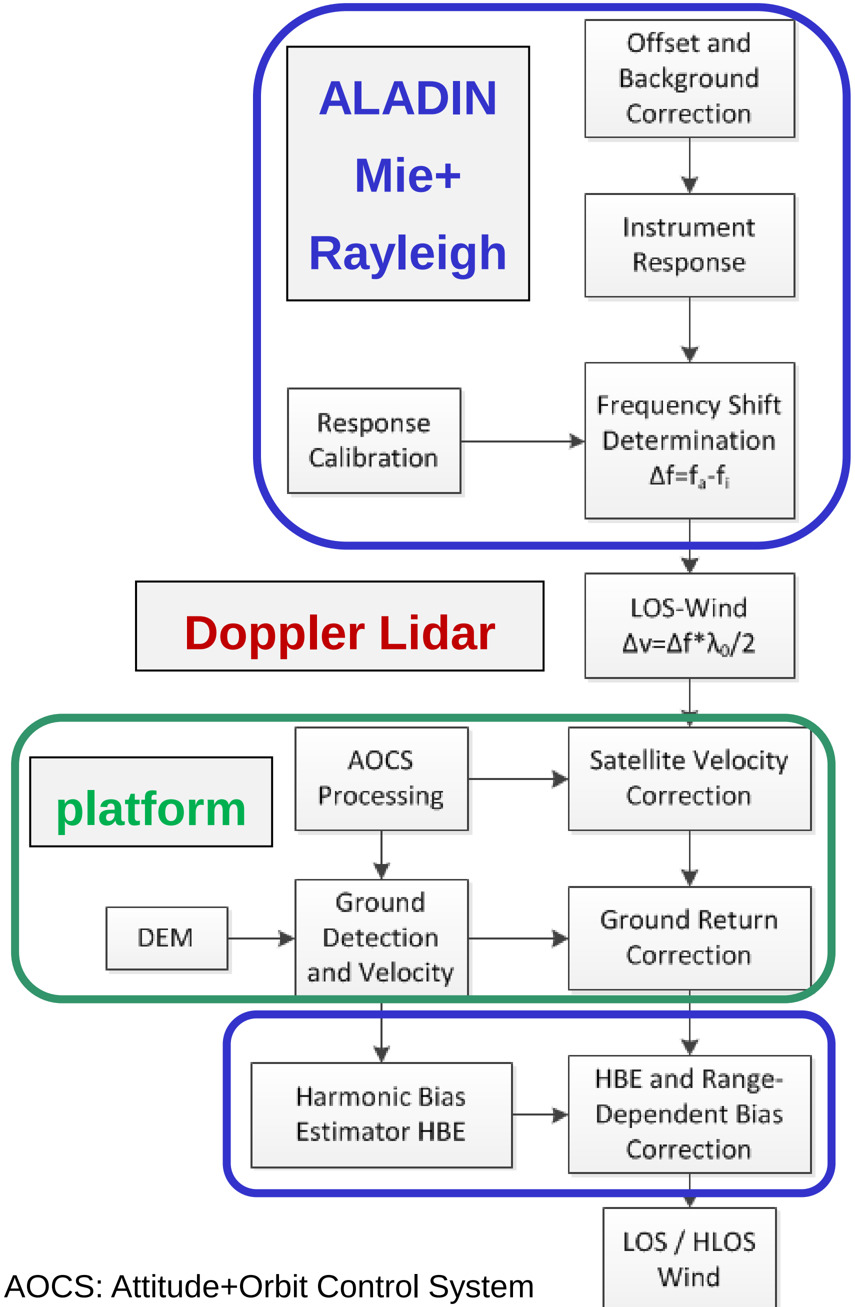








Main processing steps for wind retrieval up to Level 1



AOCS: Attitude+Orbit Control System
DEM: Digital Elevation Model

$$
\begin{aligned}
\Delta f_{ALADIN} &= \Delta f_{LOS,atmos} + \Delta f_{LOS,sat} + \Delta f_{offset} \\
&= \Delta f_{atmos} - \Delta f_{internal}
\end{aligned}
$$

L1 Wind Mode Data

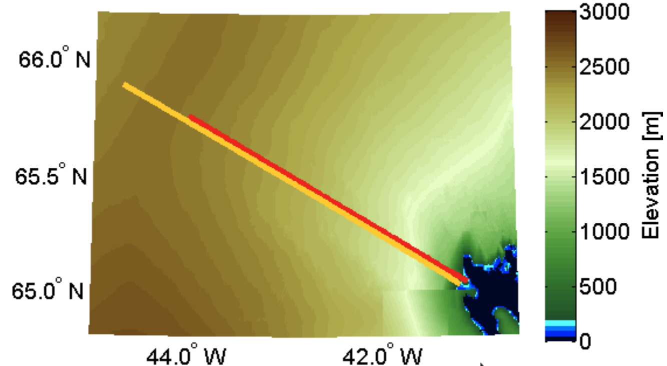
- all instrument related corrections and calibrations
- both Mie and Rayleigh winds
- no atmospheric corrections, e.g. temperature, pressure, aerosol cross-talk to Rayleigh => L2 product
- no scene classification or grouping => L2 product

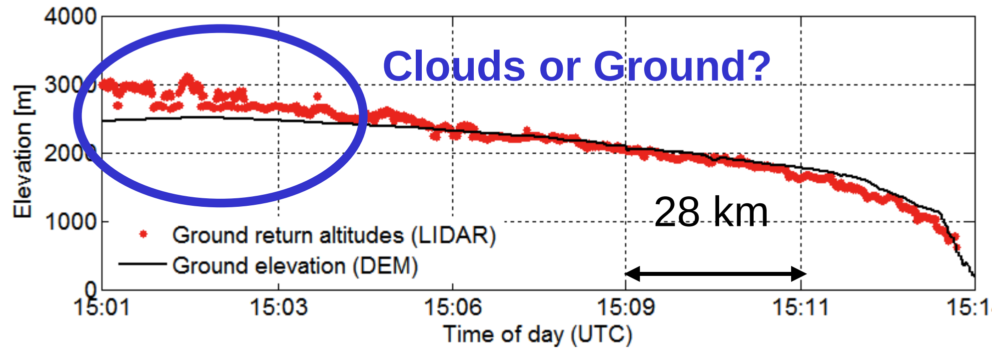
Additional L1 Data

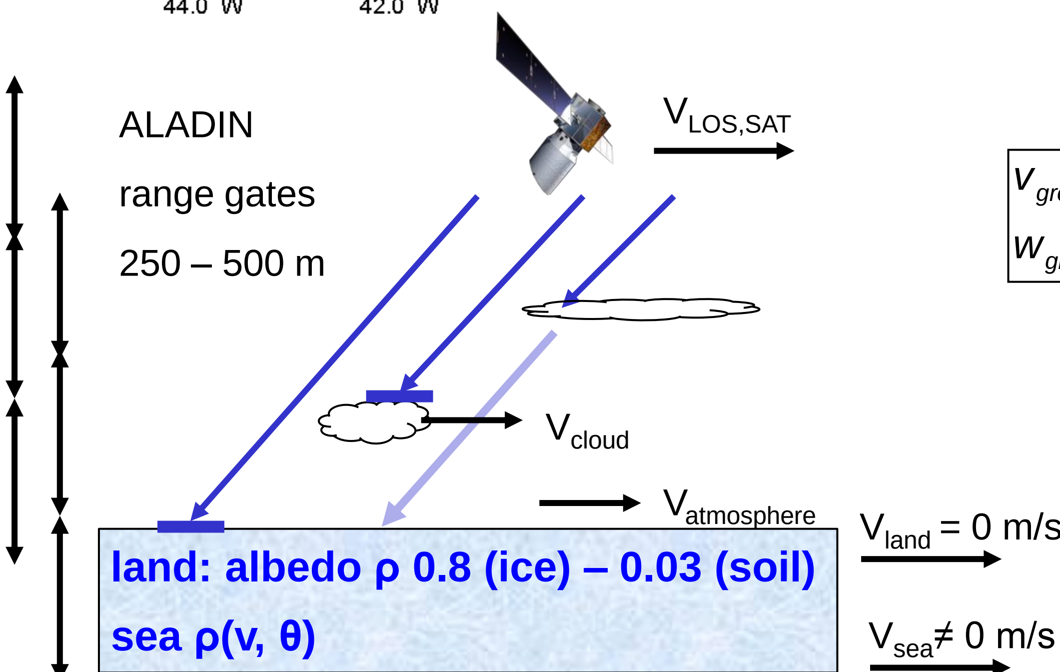
- Geolocation
- Signal amplitudes and SNR
- Error quantifiers and quality flags
- Geolocation, pointing, instrument data
- Ground-return signal and velocity

Unique calibration target for space-/airborne wind lidars: the (non-)moving ground

A2D in Greenland 2009







ALADIN ground speed

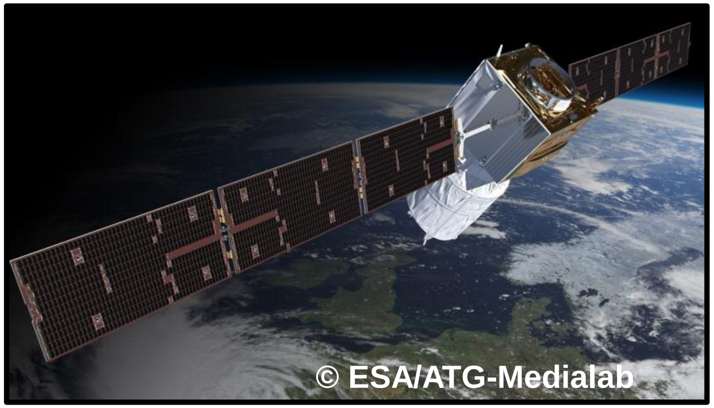
$$v_{ground} = w_{ground} \cdot v_{LOS,Sat} + (1 - w_{ground}) \cdot v_{atmos,cloud}$$
$$w_{ground} = f(\Delta R, R, \beta_{atmos,cloud}, \rho_{land})$$

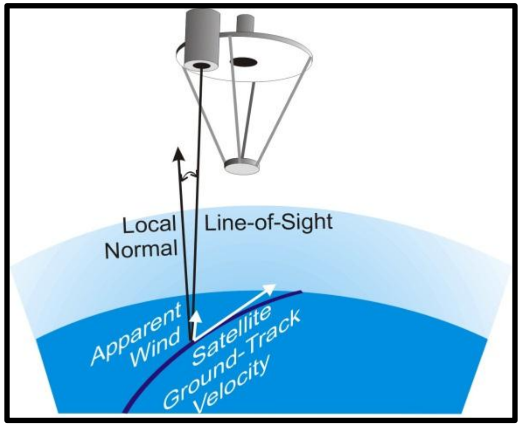
- correction of residual satellite speed
- Mie and Rayleigh response calibration in nadir pointing mode
- ALADIN bias corrections

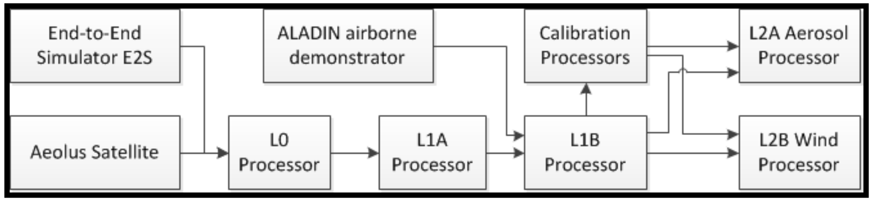
Key challenges for wind retrieval from Aeolus

processing	purpose	challenge
Rayleigh offset corrections	wind derived from signal I	1 % I = 3.5 m/s LOS => high SNR + systematic errors in I <0.05%
Mie pixel corrections (=spectral corrections)	fringe-imaging for Mie; wind derived from centroid	1 pixel = 18 m/s LOS => centroid accuracy 0.05 pixel => high SNR
Mie and Rayleigh response cal. with atmos. and ground returns	input to L1 and L2 wind retrieval	random error during calibration => systematic error for wind retrieval; characterisation of difference in optical path internal / atmosphere
Ground detection and quality-control of ground velocity	Mie/Rayleigh response cal., v_{SAT} correction, and bias characterisation	coarse range gates => atmospheric contribution
LOS wind derived from $v_{LOS} = (f_a - f_i) * \lambda_0 / 2$	principle of wind retrieval for L1 and L2	no monitoring of absolute laser wavelength, no locking to molecular line, no differential wind retrieval $v_{LOS,c} = v_{LOS} - v_0$
Bias corrections	for L1 and L2 winds	characterisation of the bias correction coefficients

Summary and Conclusion







- 2 different approaches for wind retrieval in ALADIN for molecular Rayleigh return and aerosol/cloud return
- Calibration from instrument response to frequency is needed and 2 approaches are currently implemented
- Aeolus is the first wind lidar and it will be the first time that retrieval algorithms will be challenged by real atmospheric observations from space

Reitebuch, Huber, Nikolaus: Algorithm Theoretical Baseline Document ATBD, V 4.1, July 2014